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# Physical Therapy

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## Intermanual Transfer in Training With an Upper-Limb Myoelectric Prosthesis Simulator: A Mechanistic, Randomized, Pretest-Posttest Study

Sietske Romkema, Raoul M. Bongers, Corry K. van der Sluis

S. Romkema, OT, MSc, Department of Rehabilitation Medicine, University Medical Center Groningen, University of Groningen, Hanzeplein 1, NL-9700 RB Groningen, the Netherlands. Address all correspondence to Ms Romkema at: s.romkema@umcg.nl.

R.M. Bongers, MSc, PhD, Center of Human Movement Sciences, University Medical Center Groningen, University of Groningen.

C.K. van der Sluis, MD, PhD, Department of Rehabilitation Medicine, University Medical Center Groningen, University of Groningen.

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**Background.** Intermanual transfer may improve prosthetic handling and acceptance if used in training soon after an amputation.

**Objective.** The purpose of this study was to determine whether intermanual transfer effects can be detected after training with a myoelectric upper-limb prosthesis simulator.

**Design.** A mechanistic, randomized, pretest-posttest design was used.

**Participants.** A total of 48 right-handed participants (25 women, 23 men) who were able-bodied were randomly assigned to an experimental group or a control group.

**Intervention.** The experimental group performed a training program of 5 days' duration using the prosthesis simulator. To determine the improvement in skill, a test was administered before, immediately after, and 6 days after training. The control group only performed the tests. Training was performed with the unaffected arm, and tests were performed with the affected arm (the affected arm simulating an amputated limb). Half of the participants were tested with the dominant arm and half with the nondominant arm.

**Measurements.** *Initiation time* was defined as the time from starting signal until start of the movement, *movement time* was defined as the time from the beginning of the movement until completion of the task, and *force control* was defined as the maximal applied force on a deformable object.

**Results.** The movement time decreased significantly more in the experimental group ( $F_{2,92}=7.42$ ,  $P=.001$ ,  $\eta^2_G=.028$ ) when compared with the control group. This finding is indicative of faster handling of the prosthesis. No statistically significant differences were found between groups with regard to initiation time and force control. We did not find a difference in intermanual transfer between the dominant and nondominant arms.

**Limitations.** The training utilized participants who were able-bodied in a laboratory setting and focused only on transradial amputations.

**Conclusions.** Intermanual transfer was present in the affected arm after training the unaffected arm with a myoelectric prosthesis simulator, and this effect did not depend on laterality. This effect may improve rehabilitation of patients with an upper-limb amputation.



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The rate of use of prosthetic devices in people with an upper-extremity amputation is low; approximately 30% of the potential users reject the devices.<sup>1-4</sup> This high incidence of rejection is due not only to technical limitations, but also to limitation in prosthesis skills following the injury. It has been suggested that an earlier start with prosthesis training may lead to improvement in the skill of prosthetic handling and a greater acceptance of the device.<sup>5-8</sup> However, it often is not feasible to start prosthetic training immediately after an amputation because of the time needed for wound healing, as well as time for fabrication and fitting of the prosthesis. Training immediately following amputation may be facilitated if intermanual transfer is used. Intermanual transfer has already been found to be useful in body-powered prosthetic use,<sup>9</sup> but it has never previously been tested with myoelectric prostheses. During intermanual transfer,<sup>10-13</sup> motor skills learned at one side of the body transfer to the other side. For patients with an amputation, this transfer means that training with the unaffected arm enhances the motor skills of the amputated arm.<sup>9</sup>

Intermanual transfer can be understood from the generalized motor program framework as put forth by Schmidt.<sup>14,15</sup> After training for a motor skill, a generalized motor program, defining a class of movements, is stored in memory. This motor program is used for a specific class of movements (eg, writing a signature) and contains relative variables, such as the relative timing and relative force. These variables specify the proportional time a submovement lasts within the total movement time and the proportional force a submovement exerts when compared with the total force, respectively. One example of a relative variable is the percentage of time taken to write

one letter within a signature. These relative variables remain invariant over the same class of movements. In addition, for each movement produced within a class of movements, the absolute timing and absolute force are adapted to the task demands. When performing a task such as writing, the absolute variables (ie, speed, amplitude, and muscles used) change. These parameters are not part of the generalized motor program. Within this framework, the relative parameters (ie, the parameters that remain invariant within a class of movements) can be transferred to the contralateral hand. Parameters specifying absolute time and absolute force that are tuned to the specifics of each individual movement are harder to transfer. The transfer of relative timing has been demonstrated in the literature, which supports the generalized motor program theory, whereas absolute force was harder to transfer.<sup>16-19</sup>

Weeks et al<sup>9</sup> demonstrated the learning effects of intermanual transfer in body-powered prosthetic use. In a body-powered prosthesis, the prosthetic hand is connected to a harness around the contralateral shoulder. Hand opening is directly controlled through movement of the shoulders and trunk. The current article examines intermanual transfer in myoelectric upper-limb prostheses. Hand opening and closing in a myoelectric prosthesis are controlled by activation of forearm muscles that turn on and off the electric motors. Such prostheses are indirectly controlled by activation of the muscles, contrary to the direct control of body-powered prostheses. The delay in indirect control is what makes it unnatural. Moreover, proprioceptive control of the opening of the hand is not available; therefore, the grip aperture is only perceivable through vision. This indirect control of myoelectric prostheses may affect learning how to handle these prosthe-

## The Bottom Line

### What do we already know about this topic?

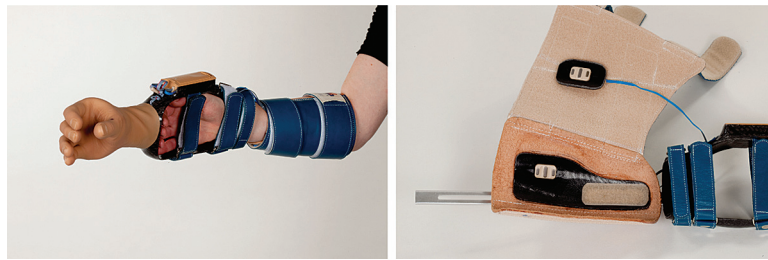
Intermanual transfer is the ability to transfer motor skills from one trained limb to the other limb. Intermanual transfer may allow people with an amputation to begin prosthetic training almost immediately after the amputation instead of waiting for the wound to heal. This study sought to determine whether intermanual transfer effects would be detected after training with a myoelectric prosthesis simulator.

### What new information does this study offer?

The results showed the presence of intermanual transfer effects in the affected arm of healthy adults after training with a myoelectric prosthetic simulator.

### If you're a patient or a caregiver, what might these findings mean for you?

After an upper-limb amputation, you can start training immediately with the unaffected side. This training might help you to improve your handling of the prosthesis.



**Figure 1.**

The myoelectric simulator attached to an unaffected arm (left) and the inside of the Velcro sleeve showing the electrodes (right).

ses,<sup>20</sup> and may influence the effect of intermanual transfer.

The number of people who have recently had an upper-limb transradial amputation and who will for the first time be provided with a myoelectric prosthesis is not large enough for a statistically relevant study. To establish the effects of intermanual transfer, we made use of participants who were able-bodied using a transradial prosthesis simulator (Fig. 1).<sup>21,22</sup> This simulator can be attached to an unaffected arm. In myoelectric control, the wrist extensors and flexors control hand opening, producing grasping profiles similar for both simulators and real prostheses.<sup>23</sup> Using a prosthesis simulator to train one arm (ie, the unaffected arm) while testing the other arm (ie, the affected arm) allowed us to study intermanual transfer of myoelectric prosthesis training in individuals who are able-bodied.

The aim of this research was to determine whether intermanual transfer effects could be detected after training with a myoelectric prosthesis simulator. Considering the generalized motor program theory, we hypothesized that when participants train with a prosthesis at one side of the body:

1. The initiation time will become shorter at the untrained side.

2. The movement time will become faster at the untrained side.
3. The force control will not improve at the untrained side.
4. Laterality was tested, because it is important for the purposes of rehabilitation to determine whether laterality affects intermanual transfer.

Furthermore, it is assumed in the literature that new and complex tasks favor the transfer from the dominant arm to the nondominant arm.<sup>18,24–26</sup> Therefore, we also hypothesized that there would be a greater improvement in movement time when the dominant hand is trained and the nondominant hand is tested than vice versa.

## Method

### Design Overview

The experimental group started with a pretest (day 1) to establish the participants' skills with their affected arm using the simulator. They then practiced for 5 days with the opposite (unaffected) arm (days 1–5). Subsequently, participants from the experimental group performed a posttest (day 5) and a retention test (day 11) using the simulator on the affected arm. The control group executed the pretest, posttest, and retention test on the same days using only the affected arm and received no training. The pretest, posttest,

and retention test consisted of 5 test tasks, each executed 3 times in random order.

### Setting and Participants

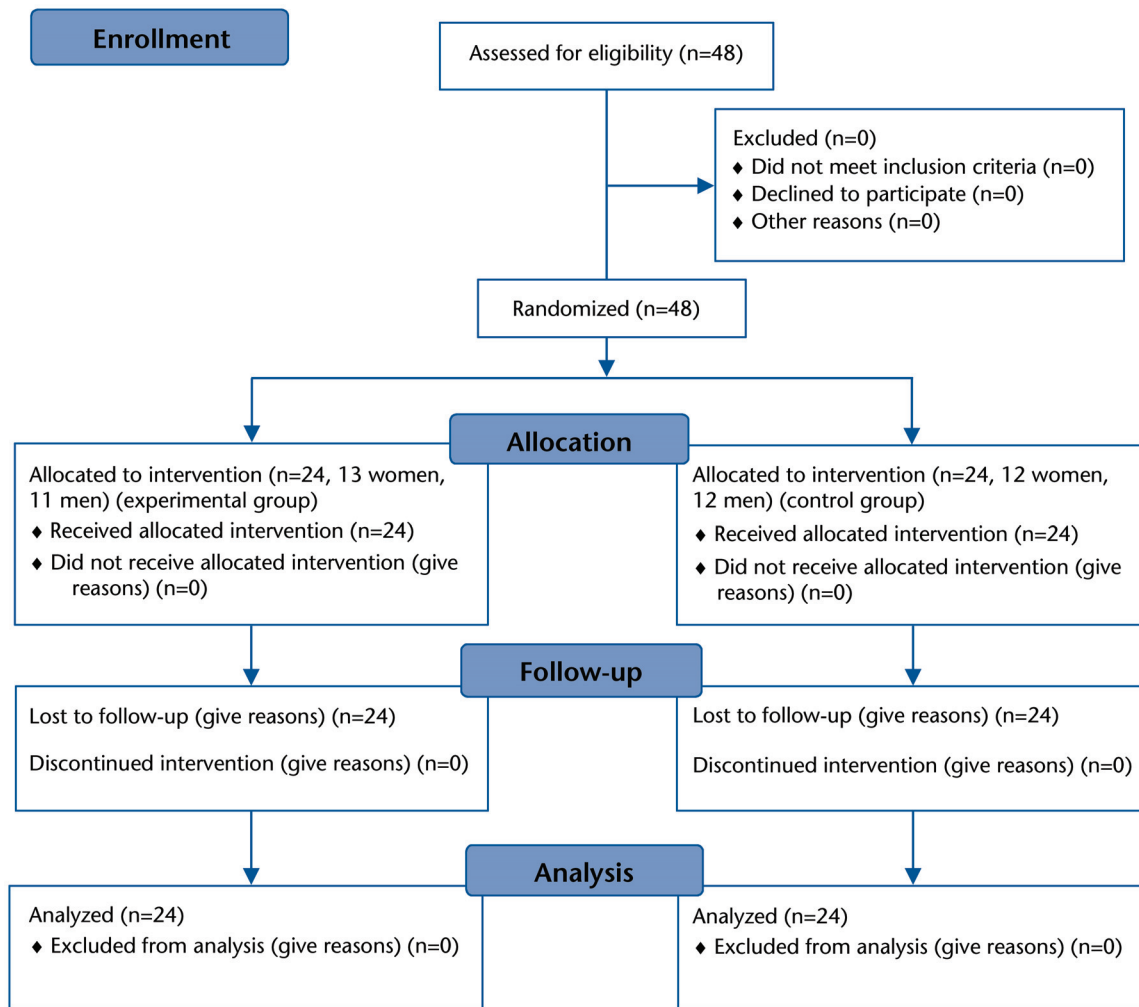
Forty-eight right-handed volunteers who were able-bodied participated (23 men, 25 women; mean age=24.6 years). All participants were free of known neurologic or upper-extremity musculoskeletal problems, had normal or corrected-to-normal vision, and had no earlier experience with the prosthesis simulator. Hand dominance was determined by self-report. All participants signed an informed consent document before participation. After completion of the experiment, participants received a gift voucher.

The myoelectric prosthesis simulator (OIM Orthopedie, Haren, the Netherlands)<sup>21,22</sup> used for the experiments consisted of a myoelectric hand (MyoHand VariPlus Speed, Otto Bock, Duderstadt, Germany) attached to an open cast in which the hand was placed (Fig. 1). The cast extended into a splint along the forearm and was adjustable in length. The splint could be attached to the arm using a Velcro (Velcro USA Inc, Manchester, New Hampshire) sleeve. The hand was controlled by changes in electrical activity related to muscle contraction, detected by 2 electrodes that were placed on the muscle bellies in the forearm. The prosthetic hand had proportional speed control (15–300 mm/s) and proportional grip force control (0–100 N).

### Randomization and Interventions

Participants were randomly assigned to 1 of 2 groups, the experimental and the control group. For half of the participants, the dominant side was tested as the affected limb, and for the other half, the nondominant side was tested as the affected limb. The CONSORT diagram presented in Fig-





**Figure 2.**  
CONSORT diagram of flow of participants in the study.

Figure 2 shows the flow of participants in the study.

All test and training sessions started with a standard procedure to fit the simulator. After palpation of wrist extensor and flexor muscles, the locations were marked with a permanent marker, and the electrodes were placed on those locations. To determine the correct location and sensitivity of the electrodes, Otto Bock's PAULA software (Otto Bock, Duderstadt, Germany) was used in conjunction with a MyoBoy (757M11 Myoboy and 13E200 Myo-

stadt, Germany) with a USB connection to a computer. With PAULA software, the muscular signals were presented on the screen. Setting the sensitivity of the electrodes required the amplified signal to exceed a threshold of 1.5 V (high signal) sustained for 2 seconds. A maximum of 5 contractions was allowed to minimize training effects. The maximum speed of the hand was set to the default setting of 6 (double-channel control, fast open, and slower closing). After the simulator was fitted, the participant was positioned in front of a table with the elbow flexed to 90 degrees. Verbal instruction on

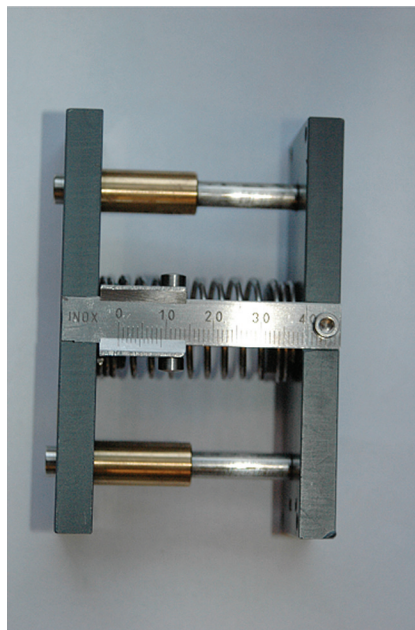
the execution of the tasks was given (see next section).

**Pretest, posttest, and retention test.** Five test tasks were performed in the pretests, posttests, and retention tests (3 functional tasks and 2 force control tasks). The test tasks took no more than 15 minutes in total to complete. During all tasks, participants sat in front of a task board (60 × 60 cm) with the start and end positions of the objects indicated on it.

The functional tasks were based on the 3 different uses of a prosthesis in

daily life<sup>27</sup>: direct grasping, indirect grasping, and fixating. For the mug task, participants were required to pick up a mug by the handle and place it 25 cm above the table on a shelf.<sup>22</sup> During the jar lid task, a jar was picked up with the unaffected hand and was passed to the prosthetic hand. The lid then had to be removed by turning it with the unaffected hand.<sup>22</sup> In the pen case task, a pencil case was held with the prosthetic hand in the starting position and the zipper was opened with the unaffected hand. E-Prime (Psychology Software Distribution, York, United Kingdom) was used to measure initiation time and movement time of these tasks (recorded in milliseconds). Before each trial, a computer screen on the left side of the participant showed which task had to be executed. A keyboard was positioned next to the task board at the side of the arm that was tested. Participants were instructed to execute all tasks as rapidly and accurately as possible. The spacebar was used to time the tasks. When the participant removed the hand, the movement was started; after executing the task, the participant pressed the spacebar again. The *initiation time* was defined as the time between the auditory tone and the release of the spacebar. The *movement time* was defined as the time between the release of the spacebar and pressing the spacebar after completing the task.

In the force control tasks, a deformable object<sup>23</sup> was to be picked up and put on a shelf 25 cm above the table; participants were instructed to compress the object as little as possible. The deformable object was made up of 2 plates (6 cm × 3.5 cm × 9 cm) with a spring in between (Fig. 3). In one condition, the spring provided a constant force of 5.31 N/mm, and in the other condition, the spring provided a constant force of 0.17 N/mm. The max-



**Figure 3.**  
Deformable object with the measurement scale.

imum deformation was measured by reading a scale attached to the plates.

**Training sessions.** During the training sessions, participants in the experimental group trained using the tasks from the Southampton Hand Assessment Procedure (SHAP).<sup>28</sup> The SHAP evaluates functionality of hand prostheses and consists of 26 tasks (12 abstract object tasks and 14 activities of daily living tasks). Each training session with the SHAP was approximately 30 minutes in length, with each participant performing 1 session on days 1 and 5 and 2 sessions on days 2 through 4.

### Data Analysis

The means of the initiation times, movement times, and object deformations for the 3 trials in each test were calculated. The results of the pretests of the experimental and control groups were compared using a repeated-measures analysis of variance (ANOVA) with task (mug, jar lid, and pen case) as a within-subject

factor and training group (experimental and control) as a between-subject factor to examine the differences between the 2 groups.

**Hypothesis 1: initiation time.** To compare the initiation times of the experimental and control groups on the different tasks, *z* scores were used. The *z* scores were calculated for each task and were used for further analysis. A repeated-measures ANOVA on initiation time was conducted on the functional tasks, with test (pretest, posttest, and retention test) and task (mug, jar lid, and pen case) as within-subject factors and training group (experimental and control) as a between-subject factor.

**Hypotheses 2 and 4: movement time and hand dominance.** For the movement times, the *z* scores were calculated for each task. A repeated-measures ANOVA on movement time was conducted on the functional tasks, with test (pretest, posttest, and retention test) and task (mug, jar lid, and pen case) as within-subject factors and training group (experimental and control) and hand dominance (dominant and nondominant) as between-subject factors.

**Hypothesis 3: force control.** A repeated-measures ANOVA was conducted on the maximal deformation in the force control tests, with test (pretest, posttest, and retention test) and task (strong spring and light spring) as within-subject factors and training group (experimental and control) as a between-subject factor.

When sphericity was violated, the degrees of freedom were adjusted with the Greenhouse-Geisser correction. In the analyses, a significance criterion of .05 was used, and *post hoc* tests on main effects used a Bonferroni correction. The effect sizes of the significant effects were calculated according to the  $\eta^2_G$ , as described by Bakeman<sup>29</sup> and Olejnik

**Table 1.**

Means (Confidence Interval) for Initiation Times (in Milliseconds) and Movement Times (in Milliseconds) for the Functional Tasks Per Test

Variable	Experimental Group			Control Group		
	Mug	Pen Case	Jar Lid	Mug	Pen Case	Jar Lid
Initiation times						
Pretest	379 (353–405)	370 (342–397)	407 (377–438)	387 (363–411)	362 (341–384)	424 (396–453)
Posttest	352 (329–375)	338 (323–353)	371 (352–390)	367 (349–386)	359 (341–377)	389 (370–409)
Retention test	336 (323–349)	336 (318–355)	363 (345–381)	362 (348–375)	349 (331–367)	413 (388–438)
Movement times						
Pretest	7,478 (6,893–8,062)	7,513 (6,896–8,129)	8,150 (7,540–8,759)	7,309 (6,636–7,982)	6,401 (5,816–6,986)	7,790 (7,150–8,431)
Posttest	4,715 (4,420–5,010)	5,232 (4,787–5,677)	5,234 (4,906–5,562)	5,554 (5,118–5,991)	5,455 (4,976–5,933)	5,654 (5,356–5,951)
Retention test	4,180 (3,932–4,429)	4,498 (4,172–4,824)	4,461 (4,230–4,691)	5,239 (4,832–5,646)	4,725 (4,355–5,094)	5,173 (4,821–5,525)

and Algina,<sup>30</sup> and interpreted according to Cohen's recommendation of 0.02 for a small effect, 0.13 for a medium effect, and 0.26 for a large effect.<sup>31</sup> Only the effects with an effect size greater than 0.02 are reported.

### Role of the Funding Source

This study was supported by grant 60-62300-98-119 from ZonMW. The sponsor had no role in any aspect of the study design, conduct, analysis, interpretation, or reporting.

## Results

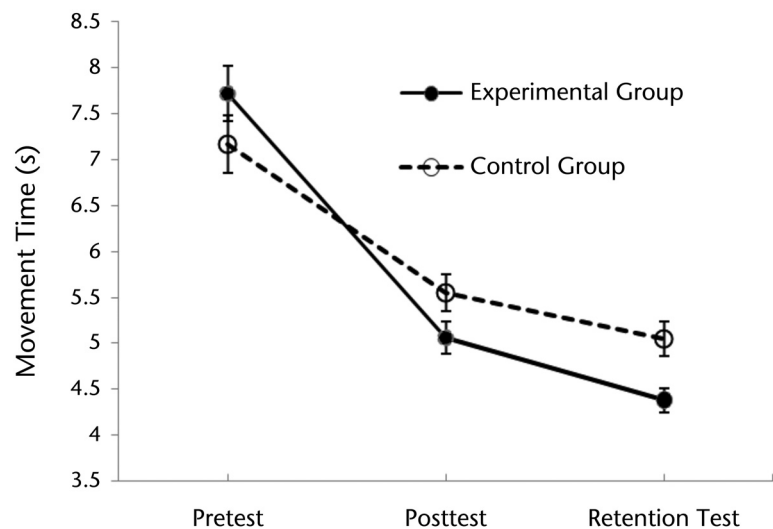
### Pretest

The ANOVAs on the pretest for initiation time, movement time, and force control data showed no differences between groups. Mean initiation and movement times are presented in Table 1.

### Functional Tasks

#### Hypothesis 1: initiation time.

The ANOVA on the initiation times showed that these times were comparable for both groups over all tests ( $F_{2,92}=2.39$ ,  $P=.097$ ,  $\eta^2=.005$ ). A significant main effect for test ( $F_{1,449,66.674}=15.74$ ,  $P=.000$ ,  $\eta^2=.038$ ) indicated that the initiation times decreased over the 3 tests. *Post hoc* analyses showed that the pretest differed from the posttest ( $P<.001$ ) and from the retention test


**Figure 4.**

Means (standard error) of the movement times (in seconds) for each of the 2 groups for all tasks over 3 tests. Real movement times are illustrated, and analyses were performed on z scores.

( $P<.001$ ). No other significant main effects or interactions were found.

#### Hypothesis 2: movement time.

The ANOVA on movement time showed that the effect of primary interest in this study, the interaction between test and group, was significant ( $F_{2,88}=7.77$ ,  $P=.001$ ,  $\eta^2=.047$ ). Three unpaired *t* tests, using a Bonferroni correction, revealed that the groups differed significantly from each other in the retention test ( $t_{46}=-2.55$ ,  $P=.014$ ), but not in the

pretest or the posttest. The decrease in movement time over sessions was greater for the experimental group than for the control group (Fig. 4). Large differences among tests ( $F_{1,344,59.156}=182.98$ ,  $P=.000$ ,  $\eta^2=.512$ ) were found. *Post hoc* analyses indicated that all tests differed significantly from each other (all  $P<.001$ ), revealing that participants were faster in the posttest and the retention test.



**Table 2.**

Mean Scores (Confidence Interval) for the Deformation (mm) of the Force Control Tasks

Measure	Experimental Group		Control Group	
	Light Spring	Strong Spring	Light Spring	Strong Spring
Pretest	14.49 (12.86–16.11)	0.61 (0.22–1.00)	15.49 (13.89–17.09)	0.63 (0.26–1.05)
Posttest	11.55 (9.94–13.18)	0.23 (0.04–0.43)	14.11 (12.50–15.72)	0.42 (0.11–0.72)
Retention test	11.02 (9.47–12.58)	0.55 (0.22–0.89)	13.56 (12.01–15.10)	0.45 (0.13–0.76)

### Force Control Tasks

**Hypothesis 3: force control.** The ANOVA on force control indicated that improvement in the 2 groups did not differ. The ANOVA showed differences among tests ( $F_{2,90}=11.28$ ,  $P=.000$ ,  $\eta^2_G=.044$ ). *Post hoc* analyses showed that the pretest differed from the posttest ( $P<.001$ ) and the retention test ( $P=.006$ ), respectively (Tab. 2). Because there were no other main effects or interactions, improvement in the 2 groups did not differ.

### Hypothesis 4: hand dominance.

In the ANOVA on movement times, no interaction effect between dominance and session was found. A main effect of hand dominance for movement time ( $F_{1,44}=10.20$ ,  $P=.003$ ,  $\eta^2_G=.14$ ) was found. Accordingly, the tasks executed with the dominant hand were performed faster (dominant hand=629 milliseconds, nondominant hand=541 milliseconds). Moreover, an interaction effect between task and test hand was found ( $F_{2,88}=10.51$ ,  $P=.000$ ,  $\eta^2_G=.05$ ). Three unpaired *t* tests, using Bonferroni correction, revealed faster performance with the dominant hand in the mug ( $t_{46}=-3.54$ ,  $P=.001$ ) and pen case tasks ( $t_{46}=-3.99$ ,  $P=.000$ ). The jar lid task was performed equally fast for both hands.

## Discussion

In this study, the intermanual transfer effects after training with an upper-limb myoelectric prosthesis simulator were tested according to the generalized motor program. We

expected that initiation times would decrease significantly after training, but we had to reject this hypothesis. It is generally assumed that the execution of new tasks affects initiation time because it requires more planning. In our study, test tasks differed from training tasks, which might explain why we did not find any transfer effects of initiation time. Our second hypothesis (ie, there would be a significantly faster movement time in the experimental group) was accepted. These findings indicate that after applying intermanual transfer training, prosthesis handling generalized to tasks other than the ones used for training, despite the fact that the premovement planning of these tasks (indicated by initiation time) was not affected by training. The control of the force (third hypothesis) did not show significant differences in improvement. The results from the second and third hypotheses were in agreement with theoretical considerations.<sup>14,15</sup> The analyses on hand dominance for the movement time (fourth hypothesis) showed that the intermanual transfer effect was symmetrical in myoelectric prosthetic training. Most authors find laterality effects favoring one direction, indicating that the dominant side benefits more from training the nondominant side<sup>26,32–34</sup> and, occasionally, vice versa.<sup>35–38</sup> Several reasons are suggested for the laterality, such as asymmetric neural architecture,<sup>18,37</sup> movement parameters or nature of the task,<sup>32</sup> and complexity or novelty of the task.<sup>18,24–26</sup> Comparable to the findings of Teixeira<sup>18</sup> and Weeks et al,<sup>9</sup> differences

in laterality were not found in the performance of a complex task. Hence, our expectations were not confirmed.

A weakness of this study is that we performed testing in an artificial situation. We did not test whether transfer effects were present in people with an amputation because only participants who were able-bodied using a prosthesis simulator were included. However, because people with an amputation generally are healthy and because the kinematic performances observed in simulators are comparable to performance with real prosthetic devices,<sup>23</sup> we expect that the intermanual transfer effects will be reproducible in people with an amputation. Furthermore, although we tried following a protocol that resembled actual clinical practice as much as possible, our investigation did not take place in a real rehabilitation setting. In our experiment, the training period was shorter in duration than the typical rehabilitation protocol, the number of tasks used was limited, and we focused specifically on transradial amputations. Nevertheless, intermanual transfer is found to be effector-independent<sup>17,39,40</sup> and thus not based on a certain task or on certain muscles. It is the effect of intermanual transfer that gives the results, independent of the task, the level of the amputation, or the muscles used.

Results of the retention test (Fig. 4), which was applied 6 days after training, showed that both groups per-

formed faster in the retention test than in the posttest. The experimental group performed the tasks 13% faster than the control group. The difference between the posttest and retention test in the experimental group has been found often in the literature.<sup>41</sup> It is commonly assumed that these changes are caused by motor memory consolidation, and thus the performances at retention are generally considered to be a better indicator of motor learning.<sup>41</sup> Although the improvement in the control group likely reflects a certain degree of the learning of how to use the prosthesis, the difference between the groups reveals the added value of the intermanual transfer resulting from training.

The additional length and weight of the prosthesis simulator alters the inertia of the limb and, therefore, the intersegmental dynamics.<sup>42</sup> However, prosthesis users are able to adapt to such perturbations.<sup>43</sup> Because in our experiment the simulator was used on both arms, the changes in intersegmental dynamics were equal on both sides, and no new adaptations needed to be learned by the participants. However, in the case of an actual prosthesis being used in a real-life setting (following an amputation), adaptations to the properties of the prosthesis and the accompanying intersegmental dynamics will have to be considered. Presumably, these changes only require adjustments to the absolute force of the learned motor program. Hence, we expect that with actual prosthesis users the intermanual transfer effects also will be found, despite the fact that the simulators used here were longer than the natural arm.

The generalized motor program theory, which was taken as the starting point in the design of this study, is not the only theory explaining the intermanual transfer effects. For

instance, the dynamical systems theory on motor coordination explains intermanual transfer from the hypothesis that the abstract coordination dynamics, containing the stable coordination modes, are instigated through learning a task.<sup>40</sup> When performing the same task with a different effector, these coordination dynamics interact with the dynamics of this new effector and the available information to create the actual behavior. This paradigm has been developed mainly for rhythmic tasks but also can be applied to discrete movements,<sup>44,45</sup> much like those used in our experiment. For instance, Zaal et al<sup>45</sup> suggested that hand opening and hand closing are 2 stable attractors whose stability is regulated by time to contact the object. Although Zaal et al<sup>45</sup> developed this notion for natural prehension, it also should work for prosthetic grasping because opening and closing the hand also are stable behaviors. From this perspective, it could be argued that abstract coordination dynamics, containing the stable states of hand opening and hand closing, are set up during training. These abstract dynamics will interact with the specific dynamics of the untrained effector in the posttest, transferring the learned skill to the untrained effector.

Hence, our findings on movement time and force control are explicable within this framework. However, intermanual transfer has not been studied thoroughly within the dynamic systems approach, making it difficult to formulate specific hypotheses, such as those concerning transfer of force. It is this reason that makes the generalized motor program theory more applicable.

The design of our study resembled rehabilitation practice more than previous studies on intermanual transfer. For instance, training was extended over several days, the tasks

used were complex and included activities of daily living tasks, and the test and training tasks differed from each other in order to examine generalizability of the training. Pereira et al<sup>46</sup> also studied intermanual transfer in complex tasks over several days, but found only small improvements. Their findings presumably were due to the fact that they examined training of general hand function in people who were healthy, which is already a well-developed skill. Weeks et al<sup>9</sup> studied prosthetic training with a body-powered prosthesis, although only with 1 day of training and using the same test and training tasks. They found improvements of initiation time and movement time, indicating improvement in both the planning and performance of the tasks. Our study was the first to reveal intermanual transfer effects in myoelectric prostheses. We demonstrated improvement in movement times of new tasks, which reveals that intermanual transfer influenced overall handling of the prosthesis. Thus, we succeeded in detecting intermanual transfer effects despite a more complicated and extended experimental setup in comparison with other studies.<sup>9,46</sup>

The main argument supporting the inclusion of intermanual transfer in rehabilitation is that by using a simulator, training of people with an upper-limb amputation can start earlier, which may lead to increased use of upper-limb prostheses.<sup>8</sup> Patients with amputations may start using their prostheses at higher performance levels, which is likely to increase motivation as well as the use and acceptance of the prosthesis.<sup>5-8</sup> To apply research on intermanual transfer to clinical practice, it is necessary for clinicians to obtain a prosthesis simulator (further training not required). Although we realize that fitting a real prosthesis directly after the amputation is preferable, in many patients this practice is not fea-

sible due to healing wounds and accompanying edema or because of the costs of temporary prostheses. In these cases, applying intermanual transfer effects might be a valuable addition to current rehabilitation practice.

Further research should focus on different aspects of the training to improve the intermanual transfer effects that we have found. Future research that we are currently planning examines timing and duration, as well as the specific tasks that optimize the effect of intermanual transfer. Furthermore, insight into the kinematic performances should increase understanding of the underlying processes. With these future studies, the clinical relevance of our findings for patients with upper-limb amputation may become clearer.

## Conclusion

Intermanual transfer effects were present after training with a myoelectric prosthesis simulator in individuals who were healthy. The initiation time did not show intermanual transfer effects, presumably because of the differences in training tasks and test tasks. The movement time showed intermanual transfer effects, whereas the force control did not. Finally, no laterality effects were found. These findings suggest that intermanual transfer might be of clinical relevance for people with an upper-limb amputation because intermanual transfer training would enable them to start prosthetic training shortly after the amputation.

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## References

- 1 Biddiss EA, Chau TT. Upper limb prosthesis use and abandonment: a survey of the last 25 years. *Prosthet Orthot Int*. 2007; 31:236–257.
- 2 Dudkiewicz I, Gabrielov R, Seiv-Ner I, et al. Evaluation of prosthetic usage in upper limb amputees. *Disabil Rehabil*. 2004;26:60–63.
- 3 Kyberd PJ, Davey JJ, Morrison JD. A survey of upper-limb prosthesis users in Oxfordshire. *J Prosthet Orthot*. 1998;10:85–91.
- 4 Plettenburg DH, ed. *Upper Extremity Prosthetics, Current Status and Evaluation*. Amsterdam, the Netherlands: Delft University Press; 2002.
- 5 Atkins D. Adult upper limb prosthetic training. In: Bowker HK, Michael JW, eds. *Atlas of Limb Prosthetics: Surgical, Prosthetic, and Rehabilitation Principles*. 2nd ed. Rosemont, IL: Mosby-Year Book; 1992: 277–292.
- 6 Dakpa R, Heger H. Prosthetic management and training of adult upper limb amputees. *Curr Orthop*. 1997;11:193–202.
- 7 Gaine WJ, Smart C, Bransby-Zachary M. Upper limb traumatic amputees: review of prosthetic use. *J Hand Surg Br*. 1997;22: 73–76.
- 8 Malone JM, Fleming LL, Roberson J, et al. Immediate, early, and late postsurgical management of upper-limb amputation. *J Rehabil Res Dev*. 1984;21:33–41.
- 9 Weeks DL, Wallace SA, Anderson DI. Training with an upper-limb prosthetic simulator to enhance transfer of skill across limbs. *Arch Phys Med Rehabil*. 2003;84:437–443.
- 10 Hicks RE, Gualtieri CT, Schoeder SR. Cognitive and motor components of bilateral transfer. *Am J Psychol*. 1983;96:223–228.
- 11 Karni A, Meyer G, Rey-Hipolito C, et al. The acquisition of skilled motor performance: fast and slow experience-driven changes in primary motor cortex. *Proc Natl Acad Sci U S A*. 1998;95:861–868.

- 12 Kumar S, Mandal MK. Bilateral transfer of skill in left- and right-handers. *Laterality*. 2005;10:337–344.
- 13 Lee M, Hinder MR, Gandevia SC, Carroll TJ. The ipsilateral motor cortex contributes to cross-limb transfer of performance gains after ballistic motor practice. *J Physiol*. 2010;558(pt 1):201–212.
- 14 Schmidt RA. A schema theory of discrete motor skill learning. *Psychol Rev*. 1975;82: 225–260.
- 15 Shea CH, Wulf G. Schema theory: a critical appraisal and reevaluation. *J Mot Behav*. 2005;37:85–101.
- 16 Inui N. Lateralization of bilateral transfer of visuomotor information in right-handers and left-handers. *J Mot Behav*. 2005;37:275–283.
- 17 Park JH, Shea CH. Effector independence. *J Mot Behav*. 2002;34:253–270.
- 18 Teixeira LA. Timing and force components in bilateral transfer of learning. *Brain Cogn*. 2000;44:455–469.
- 19 Christou EA, Rodriguez TM. Time but not force is transferred between ipsilateral upper and lower limbs. *J Mot Behav*. 2008;40:186–189.
- 20 Bongers RM, Kyberd PJ, Bouwsema H, et al. Bernstein's levels of construction of movements applied to upper limb prosthetics. *Prosthet Orthot Int*. 2012;24:67–76.
- 21 Bouwsema H, van der Sluis CK, Bongers RM. Learning to control opening and closing a myoelectric hand. *Arch Phys Med Rehabil*. 2010;91:1442–1446.
- 22 Bouwsema H, van der Sluis CK, Bongers RM. The role of order of practice in learning to handle an upper-limb prosthesis. *Arch Phys Med Rehabil*. 2008;89:1759–1764.
- 23 Bouwsema H, Kyberd PJ, Hill W, et al. Determining skill level in myoelectric prosthesis use with multiple outcome measures. *J Rehabil Res Dev*. In press.
- 24 Parlow SE, Kinsbourne M. Asymmetrical transfer of training between hands: implications for interhemispheric communication in normal brain. *Brain Cogn*. 1989; 11:98–113.
- 25 Morris T, Newby NA, Winger M, Craelius W. Inter-limb transfer of learned ankle movements. *Exp Brain Res*. 2009;192:33–42.
- 26 Parker-Taillon D, Kerr R. Manual asymmetries within the performance of a complex motor task. *Hum Move Sci*. 1989;8:33.
- 27 van Lunteren A, van Lunteren-Gerritsen GH, Stassen HG, Zuithoff MJ. A field evaluation of arm prostheses for unilateral amputees. *Prosthet Orthot Int*. 1983;7: 141–151.
- 28 Light CM, Chappell PH, Kyberd PJ. Establishing a standardized clinical assessment tool of pathologic and prosthetic hand function: normative data, reliability, and validity. *Arch Phys Med Rehabil*. 2002;83: 776–783.
- 29 Bakeman R. Recommended effect size statistics for repeated measures designs. *Behav Res Methods*. 2005;37:379–384.

- 30 Olejnik S, Algina J. Generalized eta and omega squared statistics: measures of effect size for some common research designs. *Psychol Methods*. 2003;8:434-447.
- 31 Cohen J. *Statistical Analysis for the Behavioral Sciences*. 2nd ed. New York, NY: Academic Press; 1988.
- 32 Wang J, Sainburg RL. Interlimb transfer of novel inertial dynamics is asymmetrical. *J Neurophysiol*. 2004;92:349-360.
- 33 Byrd R, Gibson M, Gleason MH. Bilateral transfer across ages 7 to 17 years. *Percept Mot Skills*. 1986;62:87-90.
- 34 Criscimagna-Hemminger SE, Donchin O, Gazzaniga MS, Shadmehr R. Learned dynamics of reaching movements generalize from dominant to nondominant arm. *J Neurophysiol*. 2003;89:168-176.
- 35 Freeman GL. Studies in the psychophysiology of transfer: III. Bilateral practice effects in normal and mirror writing. *J Exp Psychol*. 1933;16:144-160.
- 36 Ammons RB, Ammons CH. Bilateral transfer of rotary pursuit skill. *Am Psychol*. 1951; 6:294-301.
- 37 Parlow SE, Kinsbourne M. Asymmetrical transfer of braille acquisition between hands. *Brain Lang*. 1990;39:319-330.
- 38 Taylor HG, Heilman KM. Left-hemisphere motor dominance in righthanders. *Cortex*. 1980;16:587-603.
- 39 Park JH, Shea CH. Effect of practice on effector independence. *J Mot Behav*. 2003;35:33-40.
- 40 Kelso JA, Zanone PG. Coordination dynamics of learning and transfer across different effector systems. *J Exp Psychol Hum Percept Perform*. 2002;28:776-797.
- 41 Kantak SS, Winstein CJ. Learning-performance distinction and memory processes for motor skills: a focused review and perspective. *Behav Brain Res*. 2012; 228:219-231.
- 42 Sainburg RL, Ghez C, Kalakanis D. Intersegmental dynamics are controlled by sequential anticipatory, error correction, and postural mechanisms. *J Neurophysiol*. 1999;81:1045-1056.
- 43 Schabowsky CN, Dromerick AW, Holley RJ, et al. Trans-radial upper extremity amputees are capable of adapting to a novel dynamic environment. *Exp Brain Res*. 2008;188:589-601.
- 44 Schöner G. Dynamic theory of action-perception patterns: the "moving room" paradigm. *Biol Cybern*. 1991;64:455-462.
- 45 Zaal FT, Bootsma RJ, van Wieringen PC. Coordination in prehension. Information-based coupling of reaching and grasping. *Exp Brain Res*. 1998;119:427-435.
- 46 Pereira EA, Raja K, Gangavalli R. Effect of training on interlimb transfer of dexterity skills in healthy adults. *Am J Phys Med Rehabil*. 2011;90:25-34.

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## **Intermanual Transfer in Training With an Upper-Limb Myoelectric Prosthesis Simulator: A Mechanistic, Randomized, Pretest-Posttest Study**

Sietske Romkema, Raoul M. Bongers and Corry K. van der Sluis

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